**Developing a structural model for supply chain viability: a case from a developing country**

**Abstract**

 Supply chain viability can only be achieved by integrating the features of sustainability, digitalization, resilience and leagility. The Covid-19 pandemic has demonstrated the importance of viability and strengthening the effectiveness and productivity of the supply chain. Although attempts have been made to investigate this concept, the interdependencies among the factors affecting supply chain viability, particularly within the manufacturing sector in an emerging economy have not yet been explored. This study aims to fill this gap by using the Modified Total Interpretive Structural Modeling (M-TISM) methodology to develop a framework for the systematic evaluation of supply chain viability which is capable of considering the interactions and interdependencies among the viability factors, especially for application to supply chains in the manufacturing sector. The efficiency and usefulness of the proposed decision framework and model are verified in a case study. The results show that digital engagement has the most critical impact on supply chain viability, followed by energy and resource consumption and job safety and labor health. This method should be helpful to academics and industrial management, to understand what is necessary to ensure supply chain viability, especially in a developing economy, and what is needed to improve operational viability aimed at sustainable development.

***Keywords***: Supply chain viability; Modified-Total Interpretive Structural Modeling (M-TISM); Resilience; Sustainability; Digitalization

**1. Introduction**

The efficacy of the supply chain, which is marked by complex interactions, mutual dependencies and intricate feedback loops, has a great influence on nature, the economy, and society. The concepts of leagility (a combination of lean and agile) **(Ivanov 2022a; Gunasekaran et al. 2016; Dubey et al. 2015**), sustainability (Ahi & Searcy, 2013), resilience (Chowdhury & Quaddus, 2017), and digitalization (Preindl et al., 2020) in relation to supply chain efficacy have been extensively discussed in the operations and supply chain literature. Each of these paradigms has arisen in response to some inner or outer trigger. For instance, governmental regulations and pressing socio-environmental challenges have forced supply chain managers to incorporate sustainability practices into their operations as they move towards sustainable development targets (**Ahmadi et al. 2023a, b).** New approaches have had to be developed to enhance the capability, efficiency, and flexibility of supply chains following the Covid-19 disaster. *Supply chain viability is one such new approach* which considers sustainability, resilience, digitalization and leagility together (**Ivanov and Dolgui 2020).** Unfortunately, supply chains as well as economies have been negatively influenced by the pandemic and according to **Ivanov and Dolgui (2020)** it is necessary to follow certain principles and approaches in the pursuit of long-term survivability during and after disruptive event.

Recently, the consideration of human factors in the service and manufacturing sectors has attracted the attention of scholars and practitioners alike as evidenced by the appearance of more human-centric studies in operations management literature (J. Chen et al., 2021). Ogbeyemi et al. (2021) considered the significance of the human factor and survivability, in particular, with the advent of the Covid-19, within the larger framework of a holistic supply chain network system**).** The factors that affect viability form mutual dependencies and feedback loops. In addition, the resilience of a supply chain significantly influences the economic aspects of a societal system because of the extent and scope of its activities across various economic and social sectors **(Wang et al., 2014)**. Supply chain managers could take advantage of newly developed digital technologies to manage their operations, improving survivability and reliability (**Ivanov and Dolgui 2020; Dolgui et al. 2020**).

As can be seen in the above discussion, research in the supply chain field is evolving towards supply chain viability. Enhancing viability is vital in the post-pandemic era and it is believed to be the only effective way to cope with the risk of worldwide disruptions (**Yin and Ran 2021)**. According to **Ivanov (2022a),** a viable supply chain is one that is dynamically adaptable to changes. It must conform to the following four conditions: (1) it can take action to make positive changes; (2) it must be resilient to be able to cope with disruptions; (3) it can survive long-term time and finally; (4) it is in line with sustainable development targets. Supply chain viability has been explored in relation to a variety of topics by **Sardesai and Klingebiel (2023), Bag et al. (2023) and Balezentis et al. (2023**), to name a few.

 Supply chain viability is a relatively novel concept, so limited attention has thus far been paid to the interactions among its influential factors, particularly within the manufacturing sector of emerging economies. The field of supply chain management in emerging economies remains significantly underexplored (Avittathur & Jayaram, 2016) and requires more rigorous investigation. This shortfall serves as the primary impetus for the current study which endeavors to introduce an innovative assessment framework employing the Modified Total Interpretive Structural Modeling (M-TISM) technique. This approach seeks to elucidate the intricate interrelationships between the factors affecting supply chain viability. The main objectives of this study are threefold:

* To identify the key factors contributing to supply chain viability within the manufacturing sector of an emerging economy.
* To delineate and analyze the complex interrelationships and interdependencies among these viability factors.
* To propose practical managerial implications based on the findings, thereby laying the groundwork for future work in the realm of supply chain viability.

The main contributions are two-fold. First, a new evaluation framework is developed for investigating supply chain viability within the manufacturing sector in a developing economy. Second, the M-TISM methodology is employed to analyze the interdependencies and interactions among viability factors, which is a novel application in this area. M-TISM is an extension of the Interpretative Structural Modeling (ISM) method. It not only has the advantages of TISM in terms of providing some explanation for each pair of relationships between factors, but the concurrent transitivity checks carried out while constructing the initial reachability matrix also reduce the number of pair-wise comparisons required (Sushil, 2017).

 The remainder of this article is structured as follows: **Section 2** provides relevant background on the topic. **Section 3** outlines the research methodology used in this study. The analysis outcomes are presented in **Section 4**. **Section 5** consists of a discussion on the results. Limitations of the study and future research directions are addressed in **Section 6**, and lastly, Section 7 presents the concluding remarks drawn from our study.

**2. Background**

This section begins with a discussion of supply chain viability key elements. The second sub-section of literature review focuses on current works on supply chain viability.

*2.1. Supply chain viability key elements*

Viability can be explained as the supply chains’ ability to survive in a variable environment (**Yin and Ran 2021**). Viability has recently come to be considered important in supply chain management theory, because it encompasses sustainability, digitalization, resilience and leagile, particularly in the aftermath of the Covid-19 pandemic (**Ivanov and Dolgui 2020**). The key elements of viability are discussed below.

In their groundbreaking study on the leagile supply chain, Ben Naylor, Naim, and Berry (1999) provided a general definition of leagility as the convergence of lean and agile systems within a total supply chain by positioning the decoupling point to satisfy downstream needs and provide level scheduling upstream. In order to improve supply chain performance and ensure long term sustainably (Patel et al., 2018), supply chain managers have to concentrate on the Enablers of Leagility (Banerjee & Ganjeizadeh, 2017). Tamtam and Tourabi (2021) derived 15 critical enablers from a literature review including information integrity, virtualization, training and skills development of employees, and flexibility, to name a few.

In addition to the consideration of economics, and lean and agile production strategies, supply chain managers must also consider environmental and social issues. Sustainability basically means “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987) and sustainable supply chain management is defined as “the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements” (Seuring & Müller, 2008).With the growth in customer consciousness and increased concerns regarding product sustainability, organizations need to modify their approach to value creation (Ghosh et al., 2023).

In developing nations, businesses are increasingly interested in enhancing competitiveness by attaining supply chain (SC) sustainability. This requires the undertaking of diverse endeavors such as establishing information systems, creating agile networks, and embracing advanced technologies (Fu et al., 2022). Emerging technologies like cloud computing, blockchain databases, and the Internet of Things (IoT) are also being utilized, having significant ramifications for supply chain sustainability (Morella et al., 2021). Recent world-wide disruptions like that pandemic and the conflict between Russia and Ukraine, have forced businesses to reconsider how to mix the digitalization of their SCs with other sustainable methods to improve performance and reliability (Karmaker et al. 2023). Organizations are also being subjected to more and more pressure to redesign their supply chain networks in order to be compliant with sustainable development while also enhancing their resilience to deal with unanticipated disruption events.

Due to the global business interruptions, managers now have a greater need for a resilient supply chain (Mohammed et al., 2023). The concept of resilience in a production system is crucial demonstrating its ability to achieve success even in the face of failure **(Zhang & van Luttervelt, 2011)**. Supply chain resilience enables planners to proactively anticipate potential disruptions stemming from both typical and atypical events. It empowers them to efficiently address various contingencies, facilitating swift recovery and ongoing progress and development (Chowdhury & Quaddus, 2017; Lam & Bai, 2016; Pettit et al., 2010). Resilience in the context of the supply chain is measured by the ability of the supply chain to withstand change (Christopher & Peck, 2004). Resilience requires developing a range of strategies to manage disruptions effectively, such as implementing digital systems that enable efficient transmission of information across the entire digital supply chain network (**Namdar et al. 2021**).

Digitization of the supply chain could also greatly enhance its ability to recover (H. Y. Chen et al., 2019). Recovery capability refers to the supply chain's capacity to swiftly regain its initial operational level, or potentially surpass it, following the incidence of a disruptive event (Chowdhury & Quaddus, 2017). The outbreak of COVID-19 caused shutdowns and logistics disruptions, creating the need for remote work, paperless operations, and the redesign of supply chain structures. This accelerated the pace of the construction of digital supply chains to help companies quickly cope with the risk of disruption (Ardolino et al., 2022). For example, blockchain technology has been progressively utilized within the food supply chain to assist primary companies and other involved parties in monitoring and tracing the entire food production process. The blockchain technology enhances the quality of the data and information acquired by enterprises, offering an efficient information foundation for achieving visibility within the supply chain (Rogerson & Parry, 2020). This enhanced visibility assists companies in predicting risks and recognizing environmental shifts before they occur, leading to more precise market demand predictions and stronger rationale for implementing extra risk mitigation measures (Ye et al., 2022).

Recently, the concept of viability, which stands out from the conventional, stability-based understanding of resilience, has become the focus of supply chain disruption management. Resilience is defined as having the capacity to bounce back and regain a previous, stable state in order to lessen departures from some intended performance (Browning et al., 2023; Hosseini et al., 2019). According to **Ivanov and Dolgui (2020)**, while viability can significantly affect a company’s strategies to supply chain restructuring towards more resilience and leagility. For instance, a viable supply chain could switch from car manufacturing during normal times to ventilator production during a pandemic. This kind of viability thinking requires redesigning at different levels including organizational, informational, functional, and technological. The Covid-19 pandemic has led to global disruptions, and as a result, supply chain viability has been recognized as a critical objective of operations management **(Ivanov 2022a**). Viability in supply ensures long-term survivability in diverse environments **(Ivanov 2022a**). Simply being efficient and resilient is not sufficient for supply chains; they must also be viable to ensure continued operation and meet organizational needs, even in adverse and disruptive conditions (**Yin and Ran 2021**). In such situations, viability assists supply chains to achieve their long-term sustainability objectives and effectively deal with the inevitable natural disruptions (**Queiroz et al. 2022**). Immediate responses to such disruptions are essential for promoting the viability and resilience of supply chains (**Sardesai and Klingebiel 2023)**. Current works on supply chain viability are overviewed in the next sub-section.

*2.2. Current work on supply chain viability*

 The number of works in the literature analyzing supply chain viability is substantial. For example, **Lotfi et al. (2021)** studied supply chain viability network design by taking into account blockchain technology and cryptocurrency. They found that applying blockchain technology makes the supply chain more agile, leaner, more sustainable, more resilient, and reduces operational costs. **Rostami et al. (2023)** investigated viable supplier selection decisions using the goal programming-based fuzzy best worst method. **Ruel et al. (2021)** proposed an empirical measurement scale for the evaluation of supply chain viability. They discovered that supply chain viability relies on the adaptive adjustment of supply chain structures over time to ensure long-term survival. **Yin and Ran (2021)** found in their study of the internal and external capability of the blockchain-enabled supply chain that employing blockchain technology can significantly ameliorate the viability of supply chains. **Ivanov (2022b)** applied a viable supply chain model as a framework to contextualize Industry 5.0. **Alizadeh et al. (2022)** proposed a viable healthcare network design using a multi-stage stochastic methodology during the Covid-19 pandemic. **Bag et al. (2023)** explored the impact of virtue ethics and big data on enhancing the performance of viable, sustainable, digital supply chains. **Balezentis et al. (2023)** developed a frameworkfor analyzing the viability of agricultural supply chains**. Kahr (2022)** developed an optimization framework for identifying the best layouts and locations for parcel lockers and found that supply chain viability could be improved by utilizing parcel lockers. **Sheng and Saide (2021)** proposed a framework for improving the survivability of supply chains during pandemics by employing a viable system model. **Leong et al. (2022)** considered various factors associated with resilience, such as cost, lead time, quality, flexibility, and financial stability, when selecting suppliers. They utilized the grey relational analysis-best worst method-TOPSIS approach for this purpose. **Torkayesh et al. (2020)** applied several factors, including digital engagement, digital collaboration, information sharing, security, and privacy, in their study of digital supplier selection for an Iranian online store. **Galankashi et al. (2021)** considered leagible practices such as cost, quality, on-time delivery, production method and service level in their assessment of suppliers. It can be seen in the above review as well as **Table 1**, that several authors have developed frameworks for studying the concept of supply chain viability. The present study builds on the previous studies in this area by developing a new assessment framework for investigating the interactions and interrelationships among the supply chain viability factors specifically in the context of an emerging economy. A summary of the latest studies on supply chain viability can be seen in Table 1. The supply chain viability factors extracted from the literature are presented in Table 2.

**Table 1** Summary of previous studies on supply chain viability

|  |  |
| --- | --- |
| Source | Summary |
| **Lotfi et al. (2021)** | Investigated the effect of using blockchain technology on supply chain viability using a two-stage robust optimization process. |
| **Ivanov (2021)** | Developed a conceptual framework comprising four adaptation strategies designed to enhance the viability of supply chains during the Covid-19 pandemic. |
| **Ruel et al. (2021)** | Used a nomological model to develop a multi-item measurement scale for assessing supply chain viability. |
| **Yin and Ran (2021)** | Reviewed the literature on blockchain-enabled supply chain capabilities and their impact on supply chain viability. |
| **Ivanov (2022b)** | Proposed an Industry 5.0 framework from the viewpoint of supply chain viability. |
| **Alizadeh et al. (2022)** | Utilized a stochastic model to introduce a viable healthcare network design. |
| **El Korchi (2022)** | Developed a framework for analyzing the resilience, sustainability, and survivability of supply chains following the Covid-19 disaster. |
| **Liu et al. (2022)** | Studied a new multi-echelon supply chain viability problem using an optimization model |
| **Abdulrahman and Yuvaraj (2023)** | Proposed a framework for enhancing the viability in an automotive supply chain. |
| **Balezentis et al. (2023)** | Developed a framework for investigating the viability of an agricultural supply chain using a multi-criteria approach. |
| **Münch and Hartmann (2023)** | Developed a framework for investigating the effect of the Covid-19 pandemic on supply chain resilience through the analysis of multiple case studies. |
| **Sawik (2023)** | Presented a novel methodology for maintaining supply chain viability, taking into consideration the ripple effect |
| **Bag et al. (2023)** | Explored the impact of big data and virtue ethics on the performance of viable and sustainable supply chains. |
| **Nasir et al. (2022)** | Investigated the relationships between the factors that affect supply chain viability for achieving long-term sustainable development objectives in an emerging economy using Pareto analysis, grey theory, and total interpretive structural modeling. |
| **Sawik and Sawik (2023)** | Applied two stochastic optimization models to assess risk-averse viability and improve resilience of a supply chain under propagated disruptions in the context of smartphone manufacturing. |
| **Chervenkova and Ivanov (2023)** | Proposed a framework including adaptation strategies for promoting supply chain viability and carried out a case study of the global automotive manufacturing following the Covid-19 disaster. |
| **Ivanov et al. (2023)** | Reviewed the existing literature on supply chain viability, conceptualized major supply chain viability theory pillars and suggested directions for future research. |
| **Zhu et al. (2023)** | Introduced an agent-based model to simulate the viability of heterogeneous supply systems after the Covid-19 pandemic, taking into account cooperation establishment, win-win cooperation, and cooperation priority. |
| **Misbauddin et al. (2023)** | Identified the factors and developed a model for sustainable supply chain viability in an emerging economy during the pandemic, which they applied in a case study of a flower supply chain. |
| **Kähkönen et al. (2023)** | Developed a framework to explore the impact of Covid-19 on the dynamic capabilities of a corporation and supply chain resilience. |
| **Ivanov (2023)** | Proposed a decision-making framework employing digital twins for resilience analysis and specified how digital twins contribute to the development of theory in relation to supply chain resilience. |
| **Yu et al. (2023)** | Investigated the impact of digital supply chain practices on supply chain viability and operational performance during the Covid-19 disaster from the practice-based point of view. |
| **Rostami et al. (2023)** | Studied the viable supplier selection problem in an emerging economy utilizing goal programming fuzzy BWM. |

|  |  |  |
| --- | --- | --- |
| Aspects | Factor | Source |
| Leagile | Quality of products | **Alizadeh et al. (2022);** **Ahmadi et al. (2020); Ivanov and Dolgui (2020); Ivanov (2022); Leong et al. (2022); Lotfi et al. (2021); Rostami et al. (2023); Torkayesh et al. (2020); Ruel et al. (2021); Ahmadi et al. (2023a, b); Afrasiabi et al. (2022); Kumar et al. (2019); ÖZBEK and Yildiz (2020); Sheng and Saide (2021); Kahr (2022)** |
|  | Cost |
|  | Lead time |
|  | Transportation |
| Sustainability | Waste management |
|  | Energy and resource consumption |
|  | Job safety and labor health |
|  | Pollution control |
|  | Environmental management initiatives |
|  | Saving energy |
| Digitalization | Digital engagement |
|  | Information sharing |
|  | Privacy |
|  | Security |
|  | Digital production system |
| Resiliency | Network reliability |
|  | Cooperation |
|  | Backup supplier |
|  | Extra inventory |
|  | Survivability |

**Table 2** Supply chain viability factors (extracted from the literature)

**3. Methodology**

In pursuit of our research objectives, we extended invitations to 22 experts from the Iranian manufacturing sector to participate in this study. Ultimately, six of these experts graciously consented to join our expert panel. These decision-makers, from different Iranian manufacturing firms, helped in the evaluation and data collection process. They were motivated to investigate the viability of their supply chain operations. Every expert had a minimum of 15 years of practical experience in their respective field. Past studies have shown that expert-based methodologies can be effective even with a small sample size (**Rezaei et al. 2012**; **Ahmadi et al. 2023a, b; Asadabadi et al. 2023)**. The survey was conducted from March to April 2023. The decision-maker profiles are summarized in Table 3.

**Table 3** Decision-makers participating in this research

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Decision-maker | Position | Industry |  Experience (Years) | Academic degree |
| 1 | Supply Manager | Automobile  | 18 | Master’s |
| 2 | Purchasing Manager | Electronics  | 16 | Bachelor’s |
| 3 | Maintenance Manager | Tiles Manufacturing | 21 | Bachelor’s |
| 4 | Research and Development Manager | Plastics | 20 | Master’s |
| 5 | Logistics Manager | Motorcycles  | 15 | Master’s |
| 6 | Production Planning Manager | Automotive  | 19 | Master’s |

The research framework in this study is presented in **Figure 1**. The data gathering tools used in this research included a literature review, closed questionnaire, and group interviews. The first step was to uncover the viability factors mentioned in previous studies. Second, a closed questionnaire was used to refine and customize the initial list of viability factors. The supply chain viability factors were first extracted from the literature review (see Table 2) and were submitted to each of the decision-makers for their review using a survey. Furthermore, they were requested to identify which of the factors are more relevant to their company supply chain operations by indicating (+) as accepted, or (-) as rejected. The authors consulted with decision-makers and established that only those factors approved by at least four decision-makers would be considered for the subsequent review. The experts’ viewpoints are shown in Table 4.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Viability factors extracted from literature | E1 | E2 | E3 | E4 | E5 | E6 | Selected |
| Quality of products | – | + | + | + | + | + | ▄ |
| Cost | + | + | + | + | + | – | ▄ |
| Lead time | + | – | + | – | – | – |  |
| Transportation | – | – | – | + | – | – |  |
| Waste management | – | – | + | + | + | + | ▄ |
| Energy and resource consumption | + | + | + | + | + | + | ▄ |
| Job safety and labor health | + | + | + | + | – | + | ▄ |
| Pollution control | – | + | – | – | + | – |  |
| Environmental management initiatives | – | – | – | – | – | – |  |
| Saving energy | – | – | – | + | – | – |  |
| Digital engagement | + | – | + | + | + | – | ▄ |
| Information sharing | + | + | – | + | – | – |  |
| Privacy | – | – | – | – | – | – |  |
| Security | – | – | + | – | – | + |  |
| Digital production system | – | + | – | – | – | + |  |
| Network reliability | – | + | + | – | + | + | ▄ |
| Cooperation | + | + | + | + | + | + | ▄ |
| Backup supplier | – | – | – | – | – | – |  |
| Extra inventory | + | – | + | – | + | – |  |
| Survivability | – | + | + | + | + | + | ▄ |

**Table** **4** Refinement of the viability factors

The finalized list encompassed a total of nine factors (for a brief description of each factor see Table 5), which form the foundation of our evaluation framework. It is worth noting that this screening approach, which incorporates decision-maker input to determine the inclusion of specific factors in the evaluation phase, has been employed in several prior academic studies (see **Asadabadi et al. 2023**; **Ahmadi et al. 2023b; Vafadarnikjoo et al. 2021**). Third, a focus group interview method was employed to study the interrelationships among the viability factors listed in Table 5. **Parker and Tritter (2006)** suggested that the primary objective of a focus group interview is to conduct an in-depth investigation of an unfamiliar topic. Discussion in the group meeting was initiated by introducing the panelists themselves. One member of the research team took on the role of facilitator of the focus group and after introductions, provided a brief description of the project and the meaning of viability, the different dimensions, and the factors. Then, participants were asked to give their opinions about the interrelationships among these factors as a part of the M-TISM method.

**Table** **5** Evaluation framework of this study

|  |  |  |
| --- | --- | --- |
| Factors | Code | Description |
| Cost | F1 | This is related to supplier efficiency in terms of price.  |
| Quality of products  | F2 | This is related to the company’s ability in terms of quality management. |
| Waste management | F3 | Firm’s ability related to managing and diminishing waste. |
| Energy and resource consumption | F4 | This relates to the corporation’s consumption of energy and available resources. |
| Job safety and labor health | F5 | Ability to provide a healthy and safe workplace for the workforce. |
| Network reliability | F6 | Availability of suppliers, distributors, and partners before, during and after disruptions. |
| Cooperation | F7 | The ability of the firm to cooperate with other stakeholders and partners. |
| Digital engagement | F8 | This is related to the ability of the firm to harmonize digital capabilities within and beyond their physical boundaries. |
| Survivability  | F9 | Resilience during and after long-term disruptions |



**Fig. 1** Research process used in this study

 As mentioned above, Modified Total Interpretive Structural Modeling (M-TISM) was employed in this research to study the interrelationships among viability factors. M-TISM, as an extension of ISM, first introduced by Warfield in 1974, was developed by **Sushil (2017)**. M-TISM has been applied in various contexts such as finance **(Agrawal, 2020)**, innovation **(Singh & Dhir, 2022)**, and logistics **(Sindhwani et al., 2022)**. According to **Sushil (2017),** the ISM methodology lacks the capacity to provide explanations for the presence or absence of relationships between factors but the M-TISM approach offers this explanatory capability. Moreover, within the framework of M-TISM, the necessity for ad hoc examination of transitive links is obviated, as transitivity checks are inherently integrated into the preceding stages of analysis.

In addition to M-TISM, various alternative methodologies are available for the analysis of interrelationships among factors, such as the Decision-Making Trial and Evaluation Laboratory (DEMATEL), Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), and Structural Equation Modeling (SEM). Although AHP and ANP excel in determining the relative weights of factors, they require extensive pairwise comparisons. Furthermore, these methods do not offer a hierarchical modeling of interrelationships among factors. DEMATEL, on the other hand, although proficient in elucidating cause-and-effect interactions among factors, does not establish a hierarchical factor structure. Similar to AHP and ANP, DEMATEL necessitates numerous pairwise comparisons, with respondents not having not only to assess the existence but also to quantify the strength of the relationships, thereby making the data gathering process more complex. These considerations led to the choice of M-TISM as the methodology for this research.

The steps of M-TISM are provided below:

***Step 1***: identifying and defining the factors. The viability factors are extracted from a literature review and refined through expert interviews.

***Step 2***: determining the contextual relationships among the factors and the interpretation of each relationship. The contextual relationship between the viability factors is defined as "A has a positive or negative impact on B". Each expert was asked about the existence or absence of a contextual relationship between each pair of viability factors. Thus, for *k* number of factors, the total number of comparisons will be $\left[{k(k-1)}/{2}\right]$. Every comparison has two possibilities: yes or no. If there was a relationship between each pair of factors, the value of this relationship is set to 1, otherwise it is set to 0. For each confirmed relationship, experts were asked to provide the reasons for it.

***Step 3***: simultaneously carrying out transitivity checks and calculating the final reachability matrix. Since the pair-wise comparisons and transitivity checks are conducted at the same time in M-TISM, there is no clear division between the initial reachability matrix and the final reachability matrix. The subsequent questions regarding each pair of factors depend on the previous answers. The transitivity of a contextual relationship implies that if factor A has an impact on B, and B has an impact on C, then A has an indirect impact on C. It was the responsibility of the research team to check transitive relationships to avoid the experts providing extra opinions on previously discovered transitivity-based relationships. This is the main advantage of M-TISM in comparison with TISM. Figure 2 shows the efforts of the research team to provide such assistance in the pairwise comparison survey. For instance, since F2 has a direct impact on F6 and F6 directly influences F7, there was no need to ask the experts to express their opinion on the relationship between F2 and F7.

***Step 4***: level partitioning. This step is taken to assess the level of each factor based on the final reachability matrix. Three sets of factors are calculated for each viability factor. The antecedents set are those factors that influence a factor; the reachability set comprises those factors which are influenced by it. The intersection set refers to the factors that are shared by both the antecedent set and the reachability set. The factor levels are determined by first partitioning the factors for which the reachability set, and intersection set are identical. Levels are numbered beginning with one. Factors partitioned to level one are the most dependent factors. After partitioning each factor, it is removed from the rest of the level partitioning procedure. This process is continued until the levels of all factors are determined, including the most influential ones, which are partitioned.

***Step 5***: drawing the hierarchical model of the factors. A diagraph is constructed based on the final reachability matrix and level partitioning, illustrating the direct relationships between factors as well as the most significant transitive links with their corresponding explanations.

**4. Results**

The final reachability matrix developed after interviewing the experts is shown in Table 6**.** The simultaneous transitivity checks which were done during the construction of the reachability matrix are shown in Figure 2. For instance, the experts were not asked about the relationship between F7 and F6. The intersection of row F7 and column F6 which is marked with a 1\* indicates that it is indeed a transitive relationship identified without questioning the experts. This is because, as previously established based on Figure 2, it is determined that F7 influences F2, and F2 influences F6, therefore, through the transitivity rule, F7 influences F6. This is the main advantage of M-TISM, which reduces the number of queries made to the experts. In Table 6, the transitive links are indicated by 1\*.

**Table** 6 Final reachability matrix

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Names of the factors | Factors | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 |
| Cost | F1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quality of products | F2 | 0 | 1 | 0 | 0 | 0 | 1 | 1\* | 0 | 1\* |
| Waste management | F3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Energy and resource consumption | F4 | 1\* | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Job safety and labor health | F5 | 1\* | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| Network reliability | F6 | 0 | 1\* | 0 | 0 | 0 | 1 | 1 | 0 | 1\* |
| Cooperation level | F7 | 0 | 1 | 0 | 0 | 0 | 1\* | 1 | 0 | 1 |
| Digital engagement | F8 | 1\* | 1\* | 1\* | 1 | 0 | 1\* | 1 | 1 | 1\* |
| Survivability | F9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

**Direct relationships**

**Transitive relationships**

**Fig. 2** Digraph for transitivity checks

In the subsequent stage, level partitioning was performed to establish the levels of the factors by utilizing their reachability, antecedents, and intersection sets. Table 7 shows the level partitioning iterations. For example, for factor 1, the reachability matrix is $\left\{1\right\}$ and its antecedent set is $\left\{1-3-4-5-8\right\}$; therefore, its intersection set, which includes factors common to both sets, will be $\left\{1\right\}$. A factor is considered at level I if common to both the reachability set and the intersection. Once the level I factors are identified, they are removed, and the iteration process is continued to determine the levels of the remaining factors. It took three iterations to identify each factor’s level.

**Table 7** Level partitioning iterations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Factors** | **Reachability Set** | **Antecedent Set** | **Intersection Set** | **Level** |
| Iteration 1 |
| 1 | 1, | 1, 3, 4, 5, 8, | 1, | 1 |
| 2 | 2, 6, 7, 9, | 2, 6, 7, 8, | 2, 6, 7, |  |
| 3 | 1, 3, | 3, 4, 5, 8, | 3, |  |
| 4 | 1, 3, 4,  | 4, 8, | 4, |  |
| 5 | 1, 3, 5, 9, | 5, | 5, |  |
| 6 | 2, 6, 7, 9, | 2, 6, 7, 8, | 2, 6, 7, |  |
| 7 | 2, 6, 7, 9, | 2, 6, 7, 8, | 2, 6, 7, |  |
| 8 | 1, 2, 3, 4, 6, 7, 8, 9, | 8, | 8, |  |
| 9 | 9, | 2, 4, 5, 6, 7, 8, 9, | 9, | 1 |
| Iteration 2 |
| 2 | 2, 6, 7, | 2, 6, 7, 8, | 2, 6, 7, | II |
| 3 | 3, | 3, 4, 5, 8, | 3, | II |
| 4 | 3, 4, | 4, 8, | 4, |  |
| 5 | 3, 5, | 5, | 5, |  |
| 6 | 2, 6, 7, | 2, 6, 7, 8, | 2, 6, 7, | II |
| 7 | 2, 6, 7, | 2, 6, 7, 8, | 2, 6, 7, | II |
| 8 | 2, 3, 4, 6, 7, 8, | 8, | 8, |  |
| Iteration 3 |
| 4 | 4, | 4, 8, | 4, | III |
| 5 | 5, | 5, | 5, | III |
| 8 | 4, 8, | 8, | 8, | IV |

Next, the M-TISM hierarchical model was developed by using the reachability matrix and the most significant transitive links according to the experts’ opinions, as shown in **Figure 3**. Level IV contains one viability factor i.e., digital engagement. Since it is situated at the lowest level of the hierarchy, this factor can be considered the most crucial element in the proposed model. Level III includes two viability factors i.e., job safety and labor health, and energy and resource consumption. These factors impact the level II factors and are most influenced by digital engagement. In a similar manner, the factors at level II can be interpreted. The level I factors are the most dependent, mostly being the outcomes of the factors on the lower levels of the model.



**Fig. 3** M-TISM hierarchical model

**5. Discussion**

Supply chain viability is gaining significant attention from both managers and practitioners. The M-TISM technique was a useful tool for identifying and analyzing the interdependencies among different factors and developing a hierarchical model. It is observed that there are significant relationships between the identified factors contributing to supply chain viability. The developed M-TISM model shows the hierarchical structure and relationships between the factors. The factors identified as critical for supply chain viability in this study are: Digital engagement (F8), Energy and resource consumption (F4), Job safety and labor health (F5), Cooperation (F7), Quality of products (F2), Network reliability (F6), Waste management (F3), Survivability (F9) and Cost (F1). Digital engagement (F8) is situated at the lowest level, making it the most critical and influential factor in the proposed supply chain viability framework. It is followed by Energy and resource consumption (F4) and Job safety and labor health (F5). These factors possess substantial driving power in the developed model and play a crucial role in determining supply chain viability.

*5.1. Supporting literature for the M-TISM model*

In this sub-section, the most important relationships in the proposed M-TISM model are explained and supported theoretically with the aid of previous studies. Further, the logic behind each relationship is explained; see Table 8.

Digital engagement (F8)-Energy and resource consumption (F4): Today, we are observing significant advancements and a continuous rise in the use of information and communication technologies, which will eventually penetrate every aspect of human existence (**Galperova & Mazurova, 2019).** Digital technologies have been extensively employed in various sectors related to energy consumption. Digitalization affects all areas of activity and involves the integration and transformation of the energy system, enabling a better understanding of socio-economic impacts (Valeeva et al., 2022).

Cooperation (F7) & Quality of products (F2): Collaboration among entities has a significant impact on the quality of the product **(Wanagos & Marciszewska, 2018).** The quality of the relationships within the supply chain has a significant influence on both supply chain performance and product quality (Ryu et al., 2009).

Quality of products (F2) & Network reliability (F6): A high standard of manufacturing quality is a fundamental requirement for the sustained production of dependable products, and the proactive implementation of measures to ensure product reliability is critical within the manufacturing process **(He et al., 2019).** According to **Hudnurkar et al. (2014)** there are several factors the influence supply chain cooperation and trust within the network including innovative and integrative supply chain processes to provide more efficient quality products.

 Digital engagement (F8) & Cooperation (F7): Over the past few decades, there has been a noteworthy trend in China and in the Asian region towards technological progress that has paved the way for the growth of a digital economy aimed at promoting sustainability and inclusive growth. The implementation of digital technologies within conventional industries such as agriculture, manufacturing, and services, alongside nascent digital industries, has resulted in the development of new avenues for economic collaboration **(Cao, 2023).**

Digital engagement (F8) & Quality of products (F2): The development of a Supply Chain Quality Management (SCQM) process necessitates the substantial contribution of the digital supplier. This is primarily because they possess the aptitude to improve existing Quality Management Systems (QMS) in order to optimize overall organizational performance **(Sharma & Joshi, 2023)**. Digital startups have the capability to introduce new product development which becomes one of the main processes for gauging product quality **(Kencanasari & Dhewanto, 2022)**.

**Table 8.** Interpretive logic - Knowledge base

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| N | Element codes | Pairwisecomparison | Interpretation | Supporting literature |
| 1 | F8-F4 | Digital engagement will enhance energy and resource consumption | Employing digital technologies reduces demands for electricity, physical resources, manual processes, idle times, etc. | **Elena and Olga (2019); Valeeva et al. (2022)** |
| 2 | F7-F2 | Cooperation will enhance Product quality | Many initiatives in our product development projects are based on the contributions from cooperative networks inside and outside the organization | **Wanagos and Marciszewska (2018)** |
| 3 | F2-F6 | Product quality will enhance Network reliability | Most entities in our network have a long relationship with us based on the good quality of our products | **He et al. (2019)** |
| 4 | F8-F7 | Digital engagement will enhance cooperation | Digital capabilities have helped us to develop and enrich our cooperative network | **Cao (2023)** |
| 5 | F8-F2 | Transitive | We have leveraged our digital capabilities and technologies to speed up the product development processes | **Sharma and Joshi (2023); Kencanasari and Dhewanto (2022)** |
|  |  |  |  |  |

*5.2. Path analysis*

The findings of this study reveal the connections between various paths, highlighting the importance of the interrelationships between the factors impacting supply chain viability at different levels of the hierarchy. The most important paths are discussed below.

5.2.1. Path 1 [F8-F4-F3-F1]. This path identifies the relationship between Digital engagement, Energy and resource consumption, Waste management and cost. These antecedents are situated at various levels within the hierarchy. As an example, Digital engagement is located at level I in the hierarchy, while Energy and resource consumption is positioned at level 2, Waste management is at level 3, and cost is at level 4. Digital engagement helps to reduce the demands for electricity, physical resources, manual processes, idle times, etc. therefore, it affects Energy and resource consumption. Further, Energy and resource consumption affect Waste management. Any overconsumption of resources is considered a waste. Finally, Waste management will lead to a reduction in expenses at different levels which helps with supply chain viability.

5.2.2. Path 2 [F8-F7-F9]. This path identifies the relationship between Digital engagement and Cooperation and survivability. Digital engagement helps to develop and enrich the cooperative network. Further, with a cooperative network and cooperation between partners, we can achieve better reliability and ensured survivability. This is one of the factors that influence supply chain viability.

5.2.3. Path 3 [F5-F3-F1]. This path identifies the relationship between Job safety and labor health, Waste management and Cost. Job safety and labor health help with Waste management and lead to less tardiness, unproductive work, etc. Waste management also helps to cut expenses at different levels, which affects costs in turn affecting the supply chain viability.

5.2.4. Path 4 [F7-F6-F9]. This path identifies the relationship between Cooperation, Network reliability and Survivability. Cooperation influences Network reliability. The degree of cooperation is a critical factor in improving the dependability of network partners. Further, Network reliability affects Survivability which is one of the factors affecting supply chain viability.

5.2.5. Path 5 [F7-F2-F6]. This path identifies the relationship between Cooperation, Quality of product and Network reliability. Cooperative networking inside and outside of the organization helps with the quality of the product, which helps to increase access to the required resources. Good product quality ensures that members within the networks want to maintain the relationship with the company, Therefore, produce quality affects network reliability.

*5.3. Managerial implications*

The conclusion of this study makes both theoretical and managerial contributions. From a theoretical perspective, a hierarchical framework is proposed that encompasses all the factors identified as impacting supply chain viability and derives a series of propositions based on their interrelationships. From the practical standpoint, the results send a potent message to practitioners involved in the supply chain about the need for digital engagement to ensure viability within their supply chains. The second priority is given to two factors: “energy and resource consumption”, and “job safety and labor health”. In the post-Covid-19 era, these factors are significantly influenced by the level of digital engagement, leading to other viability factors, as depicted in **Figure 3**.

**6. Limitations and future research**

This work has certain limitations, which in turn, present opportunities for future research on this topic. The first concern is that only a small number of experts from a single manufacturing sector in an emerging economy were involved in the evaluation process. Our framework should be utilized in future to investigate this problem in other countries and other manufacturing sectors. We expect to observe differences in the structure of the evaluation framework and the hierarchical model using data for other countries. The second limitation is that only nine viability factors were included in the assessment framework. We suggest that, in the future, the number of factors could be increased, and several sub-factors could also be provided for more detailed analysis. Third, M-TISM was chosen as the methodological framework to address the research objectives. However, it is worth noting that alternative techniques, including the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Fuzzy Cognitive Mapping (FCM), while demanding a more extensive dataset from domain experts, remain prospective methodologies for addressing analogous research challenges in future investigations. Furthermore, focus on the most critical factors elucidated in this article might offer some effective and practical strategies for assisting decision-makers at the implementation stage to make their supply chain more viable by prioritizing these factors using Multiple Attribute Decision-Making (MADM) methods like the Analytical Hierarchy Process (AHP), Best-Worst Method (BWM), etc. Fourth, this study provides some propositions based on the links in the proposed hierarchical model (**Figure 3**) and qualitative path analysis which can be tested by employing Structural Equation Modeling (SEM) and factor analysis methods in future studies. Even, the construct of the supply chain viability could be further investigated by employing advanced regression techniques like factor analysis.

**7. Conclusion**

The COVID-19 pandemic, arguably the most severe and widespread disaster of recent times, has had a significant impact on industry and supply chains worldwide. The concept of supply chain viability which has been introduced since the pandemic, is aimed at enhancing the flexibility and efficiency of corporations and supply chains. This study is a first attempt at investigating the interdependencies and interactions among supply chain viability factors in an emerging economy, introducing a novel supply chain viability evaluation framework for analyzing the interactions among viability factors utilizing the M-TISM technique. Initially, several viability factors were extracted from a review of the literature. A panel of six industrial experts from an emerging economy was engaged for the refinement of the viability factors from which to construct the evaluation framework. Eventually, nine viability factors were included in the assessment framework. The proposed framework and model should be helpful to supply chain managers to understand the concept of viability in their supply chain operations, to make decisions about where to invest in the most critical factors to meet their targets for sustainable development. The results also have implications for supply chain viability theory and contribute to promoting effective strategies and innovative solutions for improving supply chain viability. The M-TISM methodology was employed to develop a hierarchical model of the identified factors which illustrates the interrelationships between these factors. The different paths in the model have been traced. The study findings indicate that *digital engagement* has the most substantial influence on supply chain viability, followed by *energy and resource consumption* and *job safety and labor health*. These factors have significant driving power and play a critical role in determining supply chain viability within organizations. The other critical factors, i.e., cooperation, quality of product, network reliability, waste management, survivability and cost, also play important roles in supply chain viability within the organization. **He et al. (2023)** found that digital transformation enhances firms' competitiveness and operational resilience by facilitating the coordination of human resources, information, and technology. Therefore, the role of digital engagement and digitalization is quite important for supply chain viability. Obviously, this topic is still at the initial stages of investigation, particularly in emerging economies, and needs much more attention focused on it. This work provides the foundation for a deeper analysis on this subject.

7.1. Theoretical implications

This study makes a significant contribution to current and future academic research by suggesting the factors that are effective in the supply chain viability, as well as determining the cause-and-effect relationships between these factors and determining their priority. The factors identified are, in order of importance, digital engagement, job safety and labor health, energy and resource consumption, waste management, network reliability, quality of products, cooperation, cost and survivability. A structural model is also presented, which shows the direct and indirect relationships between these factors. Especially since the global crisis of COVID-19, supply chain viability has taken on a new meaning and increasing importance, and considering these factors is essential in order to ensure the survival and viability of the supply chain over a long period of time. The occurrence of significant disruptions, in terms of both probability and timing, seems likely but remains uncertain. Such disruptions have a detrimental impact on supply chain performance, underscoring the need for rapid and effective reactions to mitigate their impacts. Therefore, paying attention to the factors presented in this study should be an effective method for improving supply chain viability in crises.

7.2. Managerial implications and lessons learned

The viability factors and the proposed structural model were confirmed by the six experts. Companies today place a high value on their suppliers' dependability and responsiveness in addition to cost and efficiency, especially given the very volatile environment in which they operate. Therefore, the strategic purchaser can nominate new suppliers based on the viability factors, such as digital engagement or waste management, as important criterion. Viability has gained prominence within contemporary supply chain management theory especially in the wake of the Covid-19 pandemic. Furthermore, an escalating inclination towards sustainability is observable in the industry. Consequently, even though companies' primary objective during crises is to sustain operations and ensure survival, they must not disregard the repercussions of their actions on both society and the environment. Not only during the COVID-19 pandemic but also in other supply chain crises, it is necessary for supply chain viability that organizations and industries take into consideration the factors identified in this study. This will enable them to navigate crises and avoid disruptions of the supply chain.

**Acknowledgment**

We thank the reviewers for the time spent on reviewing our manuscript, their careful reading and insightful comments and suggestions that have led to an improvement in the quality of this manuscript.

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